

Friction Measurement of Al-17%Si Monolithic Cylinder with Using Newly Developed Floating Liner Device

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ABSTRACT

The improvement of fuel consumption is the most important issue for engine manufactures from the viewpoint of energy and environment conservation. A piston-cylinder system plays an important role for the reduction of an engine friction. For the improvement of the frictional behavior of the piston-cylinder system, it is beneficial to observe and analyze the frictional waveforms during an engine operation.

To meet the above-mentioned demand, frictional waveforms were measured with using the renewed floating liner device. In the newly developed floating liner device, an actual cylinder block itself was used as a test specimen.

The measured single cylinder was an aluminum monolithic type made of hypereutectic Al-17%Si alloy using a high pressure die casting process. The combined piston was a light weight forged piston and a DLC coated piston ring was used. For the measurement, 110cc air cooled single cylinder engine was used.

The observed waveforms were considered to be reasonable and proper from the theoretical point of view. A friction mean effective pressure (FMEP) value was also calculated on each measurement conditions. The FMEP was increased with increasing a load of an engine operation. It was considered that the increase of the FMEP was attributable to the increase of a side force of the piston. Furthermore it was proved that the FMEP was decreased through its running-in process. The FMEP after running-in was 30% lower than that before running-in. This phenomenon was due to the change in the roughness of contact surfaces. And also the tribofilm formed on the contact surface would contribute to the reduction of the FMEP.

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INTRODUCTION

The improvement of fuel consumption is the most important issue for engine manufactures from the viewpoint of energy and environment conservation. The decrease of frictional loss is a fundamental approach for the improvement of fuel consumption. The contribution to the frictional loss of each component in an engine is investigated previously with using a motoring device. It is reported that the frictional loss of a piston-cylinder system is largest among each engine components, and the ratio to the total engine friction is estimated around 35 to 38% (1). A piston-cylinder system plays a quite important role for the reduction of the engine friction. In order to reduce the friction of the piston-cylinder system, the frictional behavior of the system during each cycle should be observed and analyzed.

For the above-mentioned purpose, a floating liner device is so effective that it has been widely used (2, 3). The schematic illustration of the conventional floating liner device is shown in [Figure 1](#). A liner which is a cylindrical sleeve is set in a cylinder block. The liner is divorced from the cylinder block and supported by load washers attached to the lower end of the liner. As the result, the liner is sustaining in the cylinder block as if it was floating. Due to this configuration, the frictional force generated in the piston- cylinder system can be measured precisely even in a firing mode.

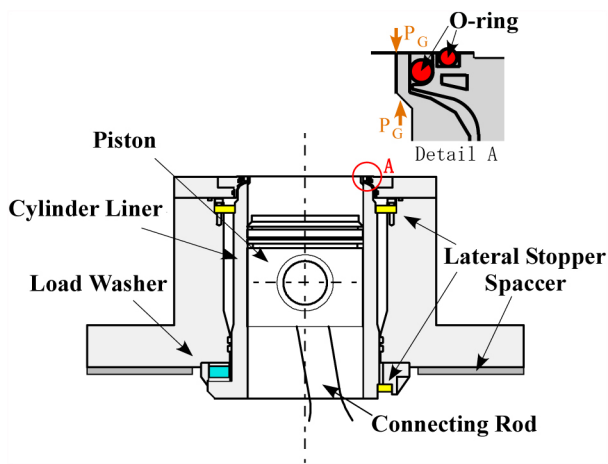


Figure 1. Conventional floating liner device.

Previously a lot of investigations are performed with using the floating liner device. Consequently the effects of a resin coating, surface roughness and skirt area on the frictional force of the piston-cylinder system are clarified (4, 5). However, among these previous investigations, measurement results of an aluminum (Al) monolithic cylinder have never been seen because it is quite difficult to prepare a thin-walled Al liner eliminating considerable distortion due to its low elasticity whereas the conventional liner for the floating liner device is made of cast iron.

Reviewing the cylinder block design, it can be categorized by cylinder bore materials and its structures as shown in Figure 2. Conventionally a cast-in or press-fitted type heterogeneous cylinder is widely used for single cylinder motorcycles mainly used in Asian countries. However, recently the monolithic type Al cylinder, named DiASil, has been widely applied for single cylinder motorcycles (6). Considering the improvement of frictional loss of DiASil cylinder, the frictional waveform of DiASil cylinder should be measured and analyzed in some way.

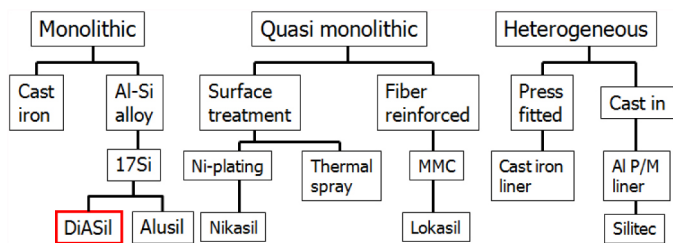


Figure 2. Categorized cylinder block design according to the cylinder bore material and its structure.

In order to meet above mentioned demand, the authors developed a renewed floating liner device using an actual Al monolithic cylinder block (7). With using the developed floating

liner device, waveforms of frictional force were measured at several engine revolutions from 3000rpm to 5200rpm. The measured waveforms showed no irregular fluctuations without any kinds of filtering processing, for example low-pass filtering and/or high-pass filtering. It revealed the enough natural frequency of the developed device for the testing condition. Consequently the obtained waveforms of frictional force were proved to be reasonable and proper.

From the above mentioned investigation, the frictional behavior of Al monolithic cylinder especially under higher engine revolution range was clarified. However, the frictional behavior at full load condition and the change in friction during running-in process have not been described. Considering the usage environment of small motorcycles, these characteristics would be important for the engine performance of the small motorcycles.

In this research, with using the renewed floating liner device originally developed by the authors (7), the frictional forces of DiASil cylinder in combination with a lightweight forged piston and DLC coated piston rings were measured with increasing the load of engine operation, then the effect of the load of engine operation on FMEP was investigated. In this paper, the FMEP was defined as a friction mean effective pressure caused by the friction between the cylinder and the piston & piston rings. Also the change in the FMEP before and after running-in process was investigated by measuring the frictional waveforms and analyzing the surface morphology.

EXPERIMENTAL

Floating Liner Device (7)

An appearance of the developed floating liner device is shown in Figure 3. Also a schematic illustration of the structure of the floating liner device is shown in Figure 4. An actual cylinder block was fixed to an outer block by 4 pieces of load washers. A frictional force acted on the cylinder block was detected with these load washers. Here, generally speaking, an increase in the cylinder weight affects the natural frequency of a measurement device, and natural frequency limit the maximum engine speed for friction measurements. The cylinder in the newly developed device was slightly heavier than that in the conventional floating liner because of using the actual cylinder block. Furthermore friction measurements under higher engine speed were required in this study. Therefore 4 pieces of load washers were required to have an enough natural frequency for friction measurements under higher engine speed. A thrust force acted on the cylinder block was supported by a lateral stopper attached at the upper and lower end of the cylinder block.

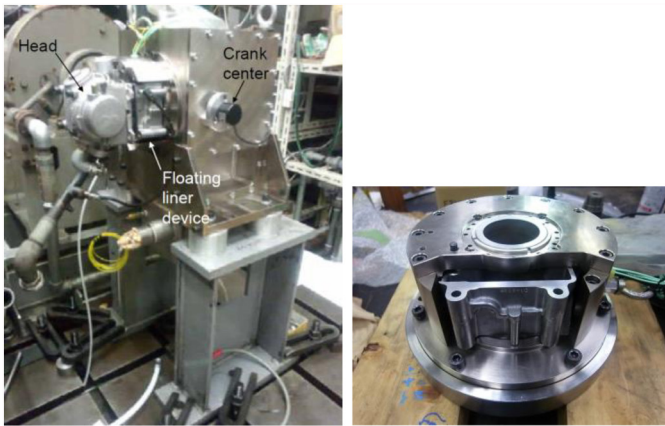


Figure 3. Developed floating liner device. Left photo: Full view of testing apparatus. Floating liner device fixed with head cylinder is attached to crankcase unit. Right photo: Appearance of floating liner unit. Cylinder block is covered with outer cylinder.

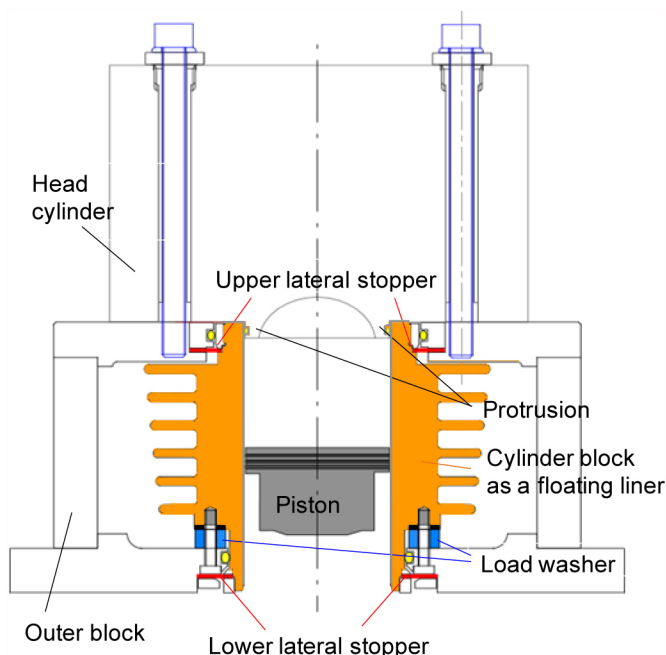


Figure 4. Schematic illustration of the structure of developed floating liner device. Connecting rod and crankcase are abbreviated from the illustration for simplification.

Generally in the floating liner device, a metallic gasket for sealing a combustion gas pressure cannot be used because the cylinder block should be “floated”. So, in the developed device, a sealing method originally proposed by Furuhashi et al. (8) was applied. That is to say, the lower surface of a cylinder head mating to the cylinder block was partially protruded into the cylinder bore, and then the O-ring was put in the groove machined on the outer surface of the protrusion of the cylinder head.

The influence of the friction between the O-ring and the cylinder bore was corrected based on a relationship between a pressure in a combustion chamber and a power output of the load washer. Furthermore the pressure in a crankcase

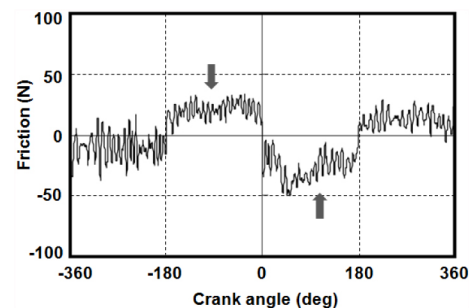
influences the power output of the load washer. The influence was also corrected with using an actual pressure measured in the crankcase.

A cooling air was blown into the space between the cylinder block and an outer block. The temperature of the cylinder block during an engine operation was measured with the thermocouple embedded near the cylinder bore surface.

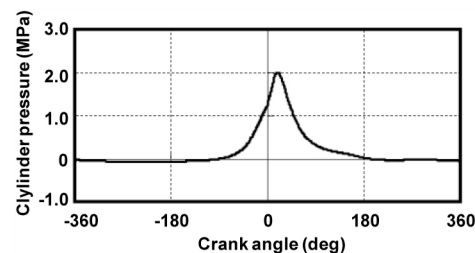
The specification of tested engine is shown in Table 1. The tested engine is 110cc air cooled single cylinder type. The cylinder bore diameter is 50mm and the stroke is 57.9mm.

Table 1. Specification of tested engine.

Bore x Stroke (mm)	50 x 57.9
Displacement (L)	0.11
Connecting rod length (mm)	93.5
Reciprocating parts mass (kg)	0.136



(a). Waveform of the frictional force.



(b). Corresponding cylinder pressure.

Figure 5. Typical waveform of the frictional force measured with using renewed floating liner device (7).

A typical waveform of the frictional force quoted from the reference (7) is shown in Figure 5(a). The horizontal axis shows a crank angle from -360° to 360° . 0° shows the point of a compressive top dead center (TDC). So, each 180° of crank angle corresponds to each engine stroke, intake, compression, expansion and exhaust. The vertical axis shows the frictional force generated between the cylinder and the piston / the piston ring set. Positive or negative value of the vertical axis shows the direction of the friction force. When the frictional force toward the TDC is generated on the cylinder bore surface, the measured frictional force is presented in positive value, and vice versa. A corresponding cylinder pressure is also shown in Figure 5(b). As well as Figure 5(a), the horizontal